dams; support angling regulations consistent with restoring ecosystem processes and functions; support additional research to address large deficiencies in information regarding steelhead freshwater and ocean life history, behavior, habitat requirements, and other aspects of steelhead biology; and provide opportunities for angling and nonconsumptive uses.

In addition, the strategy includes operating Central Valley hatcheries to protect and maintain the existing genetic diversity of naturally spawning populations and provide hatchery-produced fish for a healthy recreational fishery.

NMFS has recommended general conservation measures for steelhead throughout their Pacific coast range. These conservation measures, when applied to the Central Valley, include the following:

- Implement land management practices that protect and restore habitat. Existing practices that may affect steelhead include timber harvest, road building, agriculture, livestock grazing, and urban development.
- Review existing harvest regulations to identify any changes that would further protect Central Valley steelhead.
- Incorporate practices to minimize impacts on native populations of steelhead into hatchery programs.
- Make provisions at existing dams to allow the upstream passage of adult steelhead.
- Provide adequate headgate and staff gage structures at water diversions to control and effectively monitor water usage, and enforce water rights.
- Screen irrigation diversions affecting downstream migrating steelhead.

Within the broad context of ecosystem restoration, steelhead restoration will include a wide variety of efforts, many of which are being implemented for other ecological purposes or which are not specific to steelhead trout. For example, restoration of riparian woodlands along the Sacramento River between Keswick Dam and Verona will focus on natural stream meander, flow, and natural revegetation/successional processes. These will be extremely important in providing shaded riverine aquatic habitat, woody debris, and other necessary habitats required by lower trophic organisms and juvenile and adult steelhead populations.

Operation of the Central Valley water storage and conveyance systems for their potential ecological benefits can be one of the more important elements in restoring a wide spectrum of ecological resources, including steelhead trout.

Inadequate connectivity between upstream holding, spawning, and rearing habitat in certain tributary streams has impaired or reduced the reproductive potential of most steelhead stocks. Providing stream flows, improving fish ladders, and removing dams will contribute greatly to efforts to rebuild steelhead populations.

One critical effort will be to conduct the necessary evaluations and analyses to determine the potential benefits and consequences of reintroducing certain steelhead stocks above major dams to provide access to historic spawning and rearing areas. The potential transfer of adult fish above the dams may be straightforward, but the successful emigration downstream by juveniles cannot be ensured. Juvenile salmonid passage at large dams in the Columbia River basin has had little success and the viability of this option to protect and restore naturally spawning steelhead trout in the Central Valley is unknown.

VIABLE SALMONID POPULATION AND RECOVERY

The National Marine Fisheries Service has introduced a new and robust approach for defining the recovery of chinook salmon and steelhead stocks (NMFS 2000). Although this approach is still in the draft stage, it will be finalized and adopted as an important planning tool to ensure the recovery of listed stocks. This "viable salmonid population (VSP)" approach is designed to provide an explicit framework to identify biological requirements that will contribute to assessing management and conservation actions. The VSP introduces four sets of guidelines to determine a stocks viability.

- Population size (viable and critical levels)
- Productivity
- Spatial structure, and
- Diversity.

The VSP approach has numerous meaningful benefits for the ERP including a more accurate depiction of stock status, improved means to assess needed recovery actions, a method to evaluate completed recovery actions, a means by which to assess progress toward recovery, and a framework to organize or redefine existing recovery and management goals for steelhead trout.

INTEGRATION WITH OTHER RESTORATION PROGRAMS

- The U.S. Fish and Wildlife Service's goal, as established by the Central Valley Project Improvement Act, is to double the natural production of Central Valley anadromous fish stocks by 2002 (USFWS 1997).
- The California Department of Fish and Game is required under State legislation (The Salmon, Steelhead Trout and Anadromous Fisheries Program Act of 1988) to attempt to double the numbers of steelhead estimated to have been present in the Central Valley in 1988 (McEwan and Jackson 1996, Reynolds et al. 1993, and McEwan and Nelson 1991).
- Endangered Species Recovery Plan: The National Marine Fisheries Service is required under the federal ESA to develop and implement a recovery plan threatened Central Valley steelhead ESU and to restore this stock to levels that will allow their removal from the list of endangered species (NMFS 1997).
- California Endangered Species Act which can provide specific criteria for down listing, delisting, and recovery of listed species.

LINKAGE WITH OTHER ECOSYSTEM ELEMENTS

Steelhead trout are closely dependent on ecological processes and habitats and adversely affected by a variety of stressors. Many of the stressors affecting abundance, persistence, and recovery of steelhead were initially identified as stressors that constrain Central Valley chinook salmon populations, and were applied secondarily to steelhead because they are an anadromous fish with a generally similar life history. For the most part, stressors that affect chinook salmon also affect steelhead. However, because of the focus on chinook salmon, it is often assumed that steelhead have been affected by the identified stressors *to the same degree* as chinook salmon, hence it is a common misconception that alleviation of the stressor to the level that it no longer impacts a chinook salmon population will result in steelhead population increases. In reality, some stressors cause greater impacts on steelhead populations than they do on chinook salmon populations. For example, high water temperatures affect juvenile steelhead to a greater degree than juvenile fall-run chinook salmon because most fall-run chinook have emigrated to the ocean by early summer before high water temperatures occur, and steelhead must rear through summer and fall when water temperatures are more likely to become critical.

Important ecological processes the directly influence the health of steelhead trout or its habitat include:

- Central Valley streamflows,
- Coarse sediment supply,
- Stream meander corridors,
- Floodplain and flood processes,
- Stream temperatures,
- Bay-Delta hydraulics, and
- Bay-Delta aquatic foodweb.

Habitats used by steelhead trout during their juvenile or adult life stages include:

- Tidal perennial aquatic habitat,
- Delta sloughs,
- Midchannel islands and shoals,
- Saline and fresh emergent wetlands,
- Riparian and riverine aquatic habitats, and
- Freshwater Fish Habitats.

Stressors that adversely affect steelhead trout or its habitats include:

- Water diversions,
- Dams and other structures,
- Levees, bridges, and bank protection,
- Dredging and sediment disposal,
- Gravel mining,
- Predation and competition,
- Non-native wildlife,
- Contaminants,
- Harvest, and
- Artificial propagation programs.

OBJECTIVE, TARGETS, ACTIONS, AND MEASURES

> The Strategic Objective is to achieve, first, recovery and then large self-sustaining populations of at-risk native species dependent on the Delta, Suisun Bay, and Suisun Marsh.

SPECIES TARGETS: The Central Valley steelhead Evolutionarily Significant Unit (ESU) will be regarded as restored when the ESU meets specific viability criteria to be established in the NMFS recovery plan for Central Valley salmonids. Viability of the Central Valley steelhead ESU will be assessed according to the "Viable Salmonid Populations" (VSP) framework developed by the NMFS (in review). The framework deals with four population characteristics:

1. ABUNDANCE: populations are large enough to resist extinction due to random environmental, demographic and genetic variation.

2. PRODUCTIVITY: populations have enough reproductive capacity to ensure resistance to episodes of poor freshwater or ocean conditions and the ability to rebound rapidly during favorable periods, without the aid of artificial propagation.

3. SPATIAL DISTRIBUTION: populations are distributed widely and with sufficient connectivity such that catastrophic events do not deplete all populations and stronger populations can rescue depleted populations.

4. DIVERSITY: populations have enough genetic and life history diversity to enable adaptation to long-term changes in the environment. Populations achieve sufficient expression of historic life history strategies (migration timing, spawning distribution), are not negatively impacted by outbreeding depression resulting from straying of domesticated hatchery fish, and are not negatively impacted by inbreeding depression due to small population size and inadequate connectivity between populations.

The NMFS recovery planning for Central Valley salmonids will proceed in two phases. The first phase will be conducted by a technical recovery team (TRT) that will produce numeric recovery criteria for populations and the ESU following the VSP framework, factors for decline, early actions for recovery, and provide plans for monitoring and evaluation. The TRT will review existing salmonid population recovery goals and management programs being implemented by federal and State agencies and will coordinate with agency scientists, CALFED staff and Central Valley science/restoration teams such as the Interagency Ecological Program work teams during this first phase. TRT products will be peer-reviewed and made available for public comment.

The second phase will be identification of recovery measures and estimates of cost and time required to achieve recovery. The second phase will involve participation by agency and CALFED staff as well as involvement by a broad range of stakeholders, including local and private entities, with the TRT providing technical guidance on biological issues.

LONG-TERM OBJECTIVE: Restore self-sustaining populations of steelhead to all streams that historically supported steelhead populations and contain suitable habitat, or could contain suitable habitat with the implementation of reasonable restoration and protection measures. Numbers of fish of natural origin should exceed in most years the estimated population level in the early 1960s: 40,000 adult spawners annually.

SHORT-TERM OBJECTIVE: Determine the abundance, distribution, and structure of existing steelhead populations, and develop and implement restoration measures and protections that have a relatively high degree of certainty of increasing number and size of naturally spawning populations.

RATIONALE: Because dams have been constructed at low elevations on all major tributaries of the Sacramento and San Joaquin rivers, steelhead have been denied access to most of their historical spawning and rearing habitats in upstream areas. It was generally assumed that hatchery production would make up for any losses caused by the dams; however, hatchery production of steelhead has been limited by numerous problems. For example, one major hatchery (Nimbus) raises steelhead derived from fish imported from the Eel River and other sources because native steelhead were in short supply). Because of the hatcheries and changes to the rivers, the exact status of wild populations in the Central Valley is unclear, but the populations are certainly at low levels. The largest remaining populations of wild steelhead appear to be in the upper Sacramento River and its tributaries, but the status of these runs is unknown. Because of the severe decline of Central Valley steelhead, the NMFS has listed them as threatened under the federal Endangered Species Act. The objective, therefore, is designed to restore the numbers and spawning densities of wild steelhead to a point where the species can remain viable and can sustain a substantial sport fishery. The restoration of steelhead to reasonably high numbers and densities in currently available habitat depends on assumptions about habitat quality and the biology of the fish that need to be tested. It is likely that restoration of this fish will require providing it with access to upstream areas now blocked by dams.

STAGE 1 EXPECTATIONS: Central Valley steelhead numbers should not fall lower than they have been in the 1990s. Ongoing efforts to provide passage at impassable dams on key tributaries such as Battle, Clear, and Butte creeks should be accelerated. Water operations should provide temperatures adequate for summer rearing in reaches below the major reservoirs. Now that a hatchery marking program has been implemented so that hatchery and wild fish can be differentiated, information on the status of natural stocks can be obtained. Chinook salmon emigration studies should be augmented so that information regarding steelhead is obtained, and monitoring of adult spawner escapement on all major tributaries should be implemented. Use of the steelhead life-stage assessment protocol (see below) by the anadromous fish monitoring programs will provide valuable information on natural steelhead distribution (IEP Steelhead Project Work Team 1999).

RESTORATION ACTIONS

The following actions would help to achieve the short- and long-term restoration of Central Valley steelhead populations:

- Implement a coordinated approach to restore ecosystem processes and functions, including restoring access to historical habitat presently blocked by dams.
- Implement measures to restore habitat when restoration of ecosystem processes and functions is not feasible. This includes providing adequate flows and water temperatures in tailwater habitats below the major reservoirs.
- Protect spawning and rearing habitat in upper tributary watersheds.
- Improve riparian corridors in lower tributaries and rivers.
- Improve estuary habitat.
- Manage and operate the four hatcheries in the Central Valley that propagate steelhead in order to protect the genetic diversity of naturally and hatchery produced stocks and to minimize ecological impacts of hatchery releases on natural populations.
- Provide sufficient flows in lower tributaries for immigration and emigration to improve migration success.
- Reduce losses to unscreened diversions.
- Increase the scope of catch-and-release recreational fisheries for naturally produced steelhead. (Note: The Fish and Game Commission has adopted more stringent angling regulations for the Central Valley, including the elimination of retention of unmarked {wild} steelhead except for a limited area in the upper Sacramento River.)
- Implement programmatic actions proposed in the 14 ecological management zone visions to help achieve steelhead targets by creating and sustaining improved habitat conditions and reducing sources of mortality.

OTHER ISSUES AND INFORMATION NEEDS

The Comprehensive Monitoring, Assessment, and Research Program (CMARP - see Overview section) identifies six major knowledge gaps and monitoring needs for steelhead (CMARP Steering Committee 1999). In addition, a conceptual model was developed for Central Valley steelhead and has been incorporated into the CMARP plan as a technical appendix (IEP Steelhead Project Work Team 1999). These documents describe past research and monitoring projects for steelhead, identify what is known about their life history and status, review the adequacy of existing anadromous fish monitoring projects in terms of their ability to obtain steelhead information, and recommend new monitoring and assessment programs or enhancements to ongoing anadromous fish monitoring programs that will address the identified knowledge gaps.

The knowledge gaps are the result of institutional and natural constraints to steelhead monitoring and research. Institutional constraints are the result of the narrow focus of most anadromous fish monitoring programs: because chinook salmon are commercially exploited, highly visible, and politically sensitive, they have received the majority of limited monitoring funds and effort. This narrow focus was reinforced by the belief among resource agencies that steelhead suffer from the same level of impacts as do chinook salmon, and assessment of impacts would be similar for steelhead.

Natural constraints result from life-history traits that are common to all Central Valley steelhead that make them difficult to monitor and assess. Adults tend to migrate during high flow periods, which make it difficult to observe them and difficult to maintain counting weirs and other monitoring equipment and structures. Carcass surveys, a reliable method to estimate chinook salmon spawning escapement, is not applicable to steelhead because many survive spawning and most others do not die on the spawning grounds. Although steelhead redds can be discerned from salmon redds, they are difficult to observe because steelhead spawn at higher flows than do chinook salmon. Trap efficiencies are lower for juvenile steelhead because emigrating juveniles can more readily escape trapping because of their larger size, relative to chinook salmon.

In addition to the CMARP documents, NMFS has provided additional information regarding factors influencing the decline of steelhead, ongoing steelhead conservation efforts, and areas where clarification and additional studies are needed to provide better assurances that the actions proposed for steelhead restoration are adequate (National Marine Fisheries Service 1996a and 1996b). Information needs corresponding to the major knowledge gaps identified by the CMARP documents and other issues identified by the NMFS are described below:

CURRENT DISTRIBUTION, ABUNDANCE AND LIFE-HISTORY CHARACTERISTICS OF NATURALLY SPAWNING POPULATIONS

Existing monitoring projects have shown that naturally spawning steelhead populations exist in the upper Sacramento River and tributaries, Mill, Deer, and Butte creeks, and the Feather, Yuba, American, and Stanislaus rivers. It is possible that naturally spawning populations exist in many other streams but are undetected due to lack of monitoring or research programs.

From 1967 to 1993, run size estimates were generated for steelhead using counts at the fishway on the Red Bluff Diversion Dam (RBDD). From these counts, estimates of natural spawning escapement for the upper Sacramento River above RBDD were made. Because of impacts to winter-run chinook salmon, the operation of RBDD was changed so that the dam gates were raised earlier in the season, and this eliminated the ability to generate run-size estimates.

Beginning with broodyear 1997, all steelhead produced in Central Valley hatcheries were marked with an adipose fin clip. This program will continue as a permanent hatchery practice at these hatcheries. Marked juvenile fish were captured in smolt emigration studies beginning in 1998 and marked adult steelhead began returning in winter 1999.

The IEP Steelhead Project Work Team has developed a steelhead life-stage assessment protocol that classifies rainbow trout by developmental life stage and includes diagnostics for determining the degree of smoltification using a set of characteristics that is well-established in the scientific literature. Implementation of a standardized protocol to assign individual fish to one of several life-stage categories (yolk-sac fry, fry, parr, silvery parr, or smolt) will yield valuable information regarding when and where naturally-produced steelhead smolts occur and the disposition of juvenile steelhead through time and space. This will be an important tool in determining current distribution of steelhead throughout the Central Valley.

ACTION - More comprehensive monitoring is needed to determine system-wide distribution. In addition to existing monitoring, new projects should be initiated in the mainstem San Joaquin and Cosumnes rivers and Stony, Thomes, Antelope, and Putah creeks. For the Stanislaus, Tuolumne, Merced, and Yuba rivers and Mill and Deer creeks, the existing chinook salmon monitoring projects should be augmented so that steelhead information can be obtained. Index reaches could be established and monitored by electrofishing, beach seining, hook and line, or some other method to document occurrence, assess smolt production, and provide indices of abundance. The adult fish trap in the Daguerre Point Dam fish ladder, which is operated to monitor adult spring run chinook salmon, should be utilized to monitor adult steelhead escapement as well.

Another method of generating run-size estimates for the upper Sacramento River system, or perhaps an index, needs to be developed.

Capture of non-clipped juvenile steelhead in tributary monitoring projects will help elucidate the location of naturally spawning populations. Some existing anadromous fish monitoring projects have begun recording the life stage and the presence or absence of adipose fins on all rainbow trout observed or captured. All monitoring projects should adopt these protocols into their data collection regimen.

GENETIC AND POPULATION STRUCTURE

NMFS recently completed a genetic analysis on Central Valley steelhead as part of the west coast steelhead Endangered Species Act status review. This study provided useful information for purposes of delineation of Evolutionarily Significant Units (ESU's), but did not have the resolution necessary to provide meaningful information within ESU's, such as the Central Valley ESU. There is a need to augment this analysis to provide comprehensive information on the relationship of Central Valley steelhead populations to each other and to other populations of coastal rainbow trout. A genetic evaluation of Central Valley steelhead populations is necessary to determine phylogenetic relationships among putative native rainbow trout, naturally spawning steelhead, and hatchery steelhead that were founded from non-native broodstock. This information will be useful in estimating the structure and genetic diversity within and among Central Valley steelhead populations.

A generalized population structure can be inferred from existing knowledge of rainbow trout/steelhead life histories and behaviors, and from more specific studies on other anadromous trout population (e.g., brown and cutthroat trout). However more research into this topic is necessary to elucidate fully the interrelationship of the various life history forms, especially the non-anadromous and anadromous forms. Population ecology theory suggests that the non-anadromous forms are important for population persistence through periods of adverse climatic conditions (e.g., drought) and the anadromous forms are important for recolonizing new and restored habitat after catastrophic events (e.g., wildfires) cause the extirpation of the non-anadromous forms of a local population. This would suggest that all life-history forms of a population may be necessary for long-term persistence of the population.

ACTION - A comprehensive, basin-wide evaluation using analysis of mtDNA and microsatellite DNA structure and allele frequencies could provide information that is essential for designing recovery actions and will provide the context for successful interpretation of genetic relationships of steelhead populations in specific streams. Specific objectives of the evaluation would be:

- Evaluate and describe genetic and population structures and genetic diversity of Central Valley steelhead populations.
- Compare genetic profiles and describe phylogenetic relationship of Central Valley naturally-spawning and hatchery steelhead populations.
- Analyze genotypes of self-sustaining, putative native Central Valley rainbow trout populations that are presently isolated above artificial barriers to determine their phylogenetic relationship to anadromous and stream-dwelling rainbow trout populations and strains.
- Provide genetic information on steelhead populations of specific stream systems.

Determining maturation status of rainbow trout captured in the various monitoring projects will assist in elucidating the population structure of Central Valley steelhead and will provide much-needed information on the extent of the contribution of mature parr to the breeding population. Parr maturation, especially in males, is common in steelhead and other polymorphic salmonid populations. Sexually mature non-anadromous parr can be easily detected when working up samples of juvenile steelhead and can be easily incorporated into the steelhead life-stage assessment protocol (IEP Steelhead Project Work Team 1999). When collected systematically throughout the system in conjunction with life stage and condition, these data will provide information about the relationship of anadromous and non-anadromous forms and developmental variation in steelhead, all of which has direct bearing on population growth and dynamics.

INSTREAM FLOW NEEDS AND TEMPERATURE CONTROL

Flow needs for chinook salmon and steelhead often differ in timing; the most important flow needs for steelhead are for cold water during the summer and early fall, while increased flows for chinook typically are scheduled for the spring and mid-fall migration periods. In some cases, such as the temperature criterion for winter-run chinook from Keswick to Red Bluff, flow related actions for chinook provide appropriately timed temperature modulation for steelhead. However, this situation is a rarity. Differences in the timing and amount of flow needed by each species have the potential to lead to difficult management dilemmas in the event of extended drought.

ACTION - Workshops and research designed to contribute to developing flow-assessment protocols should pay equal attention to both steelhead and chinook salmon, and should also specifically address differences in life history between these species that require tradeoffs in flow conditions. This potential conflict should be made explicit for locations where it is most problematic (e.g., Stanislaus, American, Feather, Mokelumne, and Yuba rivers, and Cottonwood Creek). Effects of different flow regimes on habitat attributes important for each species should be evaluated for all water-year types. This information could be used to develop flow-allocation priorities where conflicts exist between the needs of both species.

A set of biological criteria including population abundance, productivity, and location should be established to guide the decision-making process. The objective should be to achieve drought protection for a well distributed set of natural populations that could serve as the source of colonists for populations that may be depleted or extirpated during a prolonged drought. Establishing priorities before a crisis exists should yield a more thoroughly considered and readily implementable course of action.

Locations where a conflict over flow allocation is less likely should also be highlighted (e.g., mainstem Sacramento from Keswick to Red Bluff, Mill, Deer, Antelope, and Butte creeks). Battle, Cow, and Clear creeks

ROLE OF INSTREAM HABITAT IN STEELHEAD PROTECTION AND RESTORATION

Temperature regulation below mainstem dams has replaced a host of other ecological and physical functions of flow as the focal point of setting flow criteria. However, maintenance of an adequate temperature regime does not provide other ecological characteristics associated with cold temperatures in upstream habitats, especially the type and availability of food resources and cover, and refugia from predatory fish. Restoration of connectivity among habitats will permit more natural movement patterns and habitat selection by steelhead juveniles and adults.

Steelhead and resident rainbow trout have been shown to utilize seasonal habitats of intermittent streams for spawning and rearing. Also, there is evidence that steelhead populations exist in some small, low elevation Sacramento River tributaries (e.g., Dry and Auburn Ravine creeks) that do not contain suitable habitat year-round, or are limiting in one or more suitable habitat characteristics. Habitat characteristics, the extent of use of these streams by steelhead, and life-history characteristics (spawning and emigration timing, size/age at emigration, etc.) is unknown.

ACTION - Given the intractability of re-creating headwaters ecology below a mainstem dam, restoration priority should be placed on both protection of intact habitats and improving access to these habitats. The second tier of priority should be degraded habitats that have the greatest potential for restoration to the combination of temperature regime and ecological function that approximate conditions in historic headwaters habitats (Pacific Rivers Council 1996).

The extent of steelhead use of intermittent and low elevation streams, habitat characteristics of these streams, and life-history characteristics (spawning and emigration timing, size/age at emigration, etc.) needs to be assessed.

RESTORATION OF ACCESS TO HISTORICAL HABITAT PRESENTLY BLOCKED BY DAMS

Because of the large-scale loss of spawning and rearing habitat that has occurred in the Central Valley, restoring access to historical habitats above impassable dams needs to be considered on some streams. This would not only increase the amount of available habitat for steelhead, but if spawning and rearing is allowed to take place in the upper reaches of a stream where it occurred historically, this may reduce the reliance on the downstream areas below the dam for spawning and rearing, and this could reduce the need to provide adequate flow and temperature conditions in the lower reach. This could have a positive impact on water storage and power generation.

ACTION - The Yuba River, and Battle and Clear creeks are locations at which evaluating opportunities to provide passage above existing barriers is most needed. Evaluation of habitat capacity above barriers is an essential first step, followed by a engineering feasibility study (Meral and Moyle 1998). In addition to the drainages named above, steelhead restoration above barriers should be pursued in at least one tributary of the San Joaquin.

Removal of barriers provides the highest probability of restoration success. However, the limited number of locations in which barrier removal is feasible, and the limited amount of habitat access provided, may be inadequate to achieve steelhead recovery. Trap, haul, and release approaches to reintroduction should not be dismissed, especially because these approaches will probably be instrumental to effective steelhead restoration in the San Joaquin and American River basins. Furthermore, over the 25 to 30 year course of the ERP, new technologies may enable implementation of trap, haul, and release approaches in locations where they are not currently considered feasible.

ASSESSMENT OF FRESHWATER PREDATION RATES

One of the ultimate factors often associated with the evolution of anadromy is escape from high predation rates on egg and juvenile life stages in the ocean environment. The relatively large egg size and low fecundity of steelhead are life-history adaptations that correspond with reduced juvenile mortality. Low freshwater predation rates are associated with headwaters habitats. Large predatory fish are more abundant and more diverse in mainstem rivers than in headwaters streams. Largemouth and smallmouth bass have been identified as important predators on juvenile chinook salmon in the Tuolumne River (EA Engineering 1992). The effect of predation by introduced striped bass is uncertain.

Paired release experiments with chinook salmon have provided information about conditions affecting freshwater survival for this species. Inferring the causative mechanisms responsible for survival patterns is an important research topic for both steelhead and chinook salmon.

ACTION - Paired release or other types of experiments conducted with steelhead smolts at different sites throughout the Central Valley could provide information on survival rates of migrating juvenile steelhead. These experiments could be incorporated into the ERP adaptive management program. The potential for protecting wild populations by manipulation of the timing and distribution of hatchery releases is one strategy that should be evaluated in these experiments. Red Bluff Diversion Dam, the Hamilton City Pumping Plant, flood bypasses, San Joaquin tributaries and mainstem, and the Delta are locations where predation rates may be high and experiments would be useful (see Gregory and Levings 1998).

Steelhead runs in the American and Feather rivers which are highly supported by hatchery production provide opportunities for using uniquely-marked parr to evaluate survival rates of rearing fish.

MAGNITUDE OF INLAND RECREATIONAL FISHERY

Large experiments with Coleman fish in 1972-73, estimated that 2.7% of the steelhead released were caught before they reached the Delta (Menchen 1980, cited in McEwan and Jackson 1996). Staley

(1976, cited in McEwan and Jackson 1996) found that 51.2% of Nimbus Hatchery yearlings released in the American River were caught. Much lower harvest rates occurred on Nimbus Hatchery fish released in the Sacramento River. Several anecdotal reports suggest that harvest rates on hatchery-stocked fish can be high.

ACTION - Considerable efforts have been made to protect steelhead by modifying recreational fishery regulations and marking all hatchery steelhead. Central Valley steelhead are now listed as threatened under the ESA, and further provisions that minimize incidental take may be necessary. These provisions include:

- Rigorous estimates, with associated error estimates, of the level of potential incidental take,
- Continued marking of hatchery-produced steelhead and retention of only marked fish,
- Specification of time periods and locations of fishing seasons to minimize incidental take,
- Availability of sanctuary areas,
- Availability of effective monitoring efforts,
- Availability of effective enforcement mechanisms and public education programs, and
- Availability of effective implementation agreements.

Given that many anglers target hatchery releases, stocking practices should be designed to avoid overlap with outmigration of wild fish.

INFLUENCE OF HATCHERY PRACTICES ON RECOVERY

Natural production of steelhead is emphasized by both State policy and the ESA. Artificial production will be limited to areas where it already occurs, where it is necessary to prevent the extinction of a native run, or where the native population has already become extirpated and the habitat is irrevocably altered (McEwan and Jackson 1996).

The hatchery percentage of total production is currently estimated at 70 to 90 % (F. Fisher, pers. comm., cited in McEwan and Jackson 1996), and this level is considered to be as high as it should get (McEwan and Jackson 1996). From 1953-54 to 1958-59 the estimated average hatchery contribution to total steelhead production was 12% (Hallock et al. 1961).

Nimbus Hatchery broodstock, and naturally spawning fish in the American River exhibit genetic affinity to populations from the Eel River (NMFS 1997), reflecting the origin of this broodstock from the Van Arsdale Fisheries Station (Busby et al. 1996). This broodstock has also been introduced to the Mokelumne River via the Mokelumne River Fish Installation (Cramer et al. 1995).

Recommendations for hatchery operations (Hard et al. 1992, NRC 1996) provide an appropriate framework for evaluation. One important issue for the Central Valley is to link recovery of native populations with decreasing production objectives for the hatchery program.

ACTION - The objective of complete marking of hatchery fish should continue without exception throughout the duration of the CALFED program.

A plan should be developed by which restoration of natural production is matched by decreases in hatchery production. Hatchery production should not attempt to compensate for poor natural production, but should instead continue or more closely serve in the role of mitigating for the loss of upstream habitat and the loss of resultant fish and not serve to increase the number of naturally spawning fish.

For example, out-of-basin broodstock should be phased out. Replacement broodstock should be developed from wild spawning anadromous steelhead or native non-anadromous rainbow trout that became isolated when the dams were constructed, if sufficient numbers are available to permit take for broodstock. Replacement with another hatchery stock that exhibits genetic association with Central Valley steelhead is preferable to continued propagation of the out of basin stock. The replacement of broodstock by native non-anadromous rainbow trout has much merit, but is premature until certain evaluations are completed. These include identifying native populations isolated above dams (one of the objectives of the comprehensive genetic evaluation is to identify these populations), and demonstrating that anadromous forms can be recreated from these populations.

FECUNDITY OF MAIDEN (FIRST-TIME) AND REPEAT SPAWNERS

Fecundity for steelhead in their initial spawning is about half the fecundity of chinook salmon (Hutchings and Morris 1985). Fecundity is positively related to body weight, and the average fecundity of repeat spawners can approximate that of chinook salmon. In addition to increased fecundity, the larger body size of repeat spawners may enable them to make a disproportionate contribution to population productivity due to: 1) ability to dig deeper, more superimposition- and scour-resistant redds, and 2) a propensity to spawn in deeper water, reducing the potential for redd dewatering.

ACTION - Fish passage facilities should be constructed to pass adult steelhead efficiently in both directions. Recreational fisheries for adults should be governed by retention of only marked fish. Success of restoration should include an evaluation of trends in proportion of repeat spawners; an appropriate target would be at least 17% reported by Hallock (1989) for upper Sacramento River samples.

ROLE OF REARING HABITAT IMMEDIATELY BELOW LARGE DAMS

Maintaining the longest possible profile of riverine habitat capable of supporting all steelhead life stages is the most desirable objective for restoration. However, numerous constraints and competing interests limit attainment of this objective, especially for juvenile steelhead. Where constraints are severe, habitat enhancement near dams may provide opportunities to improve rearing habitat capacity. Most substrate supplementation that currently occurs in the Central Valley is in the form of spawning gravel for chinook salmon. This gravel can also be used by steelhead for spawning, but it does not contribute to enhancement of steelhead rearing habitat. Juvenile steelhead prefer substrates > 4 inches in diameter (Everest and Chapman 1972, Barnhart 1986). Steelhead parr also favor microhabitat sites adjacent to relatively swift currents that have overhead cover (Fausch 1993). Overhead cover is naturally provided by undercut banks and boulders or large woody debris, but artificial structures can also provide this habitat feature. Sedimentation reduces habitat quality by reducing food production, pool depth, and cover (Barnhart 1986).

ACTION - Adding cobble substrate to areas near dams, and providing shaded riparian aquatic habitat, could increase the suitability of tailwater areas as rearing habitat for steelhead. Because maintenance of adequately cool temperatures for steelhead rearing can be accomplished with less water in the immediate vicinity of dams, this habitat enhancement could permit a reduction in the volume of cold water released by encouraging more complete use of the cool water plume.

DROUGHT PERIOD CONTINGENCY PLAN

Recent history has demonstrated the impact prolonged drought can have on fish populations, and the potential for recurring extended droughts has been documented from tree-ring data (Hunrichs 1991, cited in Mount 1995; USFWS 1995).

ACTION - An essential function of a long-term restoration plan for Central Valley steelhead is to avert population bottlenecks resulting from drought. Development of a drought contingency plan should begin with an assessment of which basins afford the greatest potential for successful use of economic incentives to maintain ample instream flows during a protracted drought. Other measures should include establishment of a drought fund that is designated for purchase of water from willing sellers and economic compensation for reduced demand in watersheds identified in the assessment phase.

ADEQUACY OF MONITORING PROGRAM

The recovery criteria found in the Proposed Recovery Plan for the Sacramento River Winter-run Chinook Salmon (NMFS 1997, Botsford and Brittnacher 1998), and the Recovery Plan for the Sacramento/San Joaquin Delta Native Fishes (1995) can be viewed as models for recovery planning. Existing recovery plans require a means for measuring natural spawner abundance (fish or redd counts) with an estimated uncertainty level, and consistent application of this monitoring procedure for an extended period. Duration of monitoring is either specified by a function of both uncertainty associated with estimation techniques and consistent attainment of abundance levels that correspond to an acceptably low probability of extinction, or attainment of specified abundance targets for a length of time often calculated as five times generation time. No recovery plan has been developed for steelhead at this time.